AD-A046 779 COLD REGIONS RESEARCH AND ENGINEERING LAB HANOVER N H F/G 13/2

ROAD SLIPPERINESS COUNTERMEASURES (GLADHEIDSBESTRIJDING),(U)

NOV 77 G M BEIJERS

UNCLASSIFIED CRREL-TL-656 NL

1 OF 1

AD A046779

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TL 656

Draft Translation 656
November 1977

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AD A046779

ROAD SLIPPERINESS COUNTERMEASURES

G.M.H. Beijers

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COLD REGIONS RESEARCH AND ENGINEERING LABORATORY
HANOVER, NEW HAMPSHIRE

Unclassified

SECURITY CLASSIFICATION OF THIS PAGE (When Data Entered)

REPORT DOCUMENTATION PAGE		READ INSTRUCTIONS BEFORE COMPLETING FORM
1. REPORT NUMBER Draft Translation 656	2. GOVT ACCESSION NO.	3. RECIPIENT'S CATALOG NUMBER
4. TITLE (and Subtitle) ROAD SLIPPERINESS COUNTERMEASURES		5. TYPE OF REPORT & PERIOD COVERED
		6. PERFORMING ORG. REPORT NUMBER
7. AUTHOR(s) G.M.H. Beijers		8. CONTRACT OR GRANT NUMBER(s)
9. PERFORMING ORGANIZATION NAME AND ADDRESS U.S. Army Cold Regions Research and Engineering Laboratory Hanover, New Hampshire		10. PROGRAM ELEMENT, PROJECT, TASK AREA & WORK UNIT NUMBERS
11. CONTROLLING OFFICE NAME AND ADDRESS		12. REPORT DATE November 1977
		13. NUMBER OF PAGES 33
14. MONITORING AGENCY NAME & ADDRESS(if different from Controlling Office)		15. SECURITY CLASS. (of this report)
		15a. DECLASSIFICATION/DOWNGRADING SCHEDULE

16. DISTRIBUTION STATEMENT (of this Report)

Approved for public release; distribution unlimited.

17. DISTRIBUTION STATEMENT (of the abstract entered in Block 20, if different from Report)

18. SUPPLEMENTARY NOTES

19. KEY WORDS (Continue on reverse side if necessary and identify by block number)

ROADS--WINTER MAINTENANCE
ROADS--TRAFFICABILITY
SNOW REMOVAL

20. ABSTRACT (Continue on reverse side if necessary and identify by block number)

The steady increase in traffic is accompanied by greater need for maintenance of the development level of the available infrastructure. The communications means of road, rail, and airfield must become steadily safer, even under winter conditions. Measures that make this possible must be ever faster, more reliable, and safer for the most important transportation routes and critical points. Because of the diversity, in regard to engineering, operational, and economic merits, of the methods presently available or under

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DRAFT TRANSLATION 656

14 CRREL-TL-656

6

ENGLISH TITLE: ROAD SLIPPERINESS COUNTERMEASURES

FOREIGN TITLE: (GLADHEIDSBESTRIJDING),

10

AUTHOR: G.M.H./Beijers

11 Nov 77

12 37p.

21 Draft Trans. of

SOURCE: Delft, Series of notes on highway engineering (e20), Delft University of Technology, Department of Civil Engineering, Feb~~ruary~~ 1973, 33p.

Translated by Office of the Assistant Chief of Staff for Intelligence for U.S. Army Cold Regions Research and Engineering Laboratory, 1977, 33p.

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ROAD SLIPPERINESS COUNTERMEASURES

From the series of notes on highway engineering (e20).

First edition.

Editor: G M H Beijers, Engr

February 1973

FOREWORD

The steady increase in traffic is accompanied by greater need for maintenance of the development level of the available infrastructure. The communications means of road, rail, and airfield must become steadily safer, even under winter conditions. Measures that make this possible must be ever faster, more reliable, and safer for the most important transportation routes and critical points.

Because of the diversity, in regard to engineering, operational, and economic merits, of the methods presently available or under development, it has occurred to bring out and take stock of what is known in practice and available in the literature for each method. The need for instruction predominated here. The intent is to give an impression of what is possible in antislipperiness measures. If this impression is indeed transferred to the reader, then this paper will have achieved its goal.

Critical comments and supplements to this first draft will be cordially welcomed, along with indication of errors. These can be incorporated in a subsequent edition.

Prof H J Th Span, Grad Engr

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1. ROAD SLIPPERINESS COUNTERMEASURES

1.1 Introduction

Slippery surfaces can occur on roadways as a result of weather, not only in winter but also in the early spring and late fall, even when the roadway itself has good adhesion. This frequently unexpectedly occurring slipperiness does not always appear, nor does it last long. Suddenly occurring slipperiness on roads is a problem for which no solution has yet been found. Obviously countermeasures must be taken against slipperiness, for the sake of highway safety. In addition, a slippery roadway slows transport of persons and goods on the road, so that economics will always demand measures against slipperiness, aside from material damage to vehicles through accidents caused by skidding.

Up to the present, the attitude has been that on one hand the best possible countermeasures must be the objective, and on the other hand wherever possible preference should go to prevention of slipperiness instead of combatting it. It is especially difficult to prevent slipperiness on a nationwide scale, because it depends too much on the very uncertain climate here. The use of slipperiness warning devices must be viewed as a first step toward responsible preventive measures against slipperiness.

Measures against slipperiness in cities and towns and on the highway scarcely differ in essence or in the speed with which they must be instituted. The main arteries in a city or town can in this regard be compared to the primary highways. Measures to counter slipperiness should be applied to this category of road as quickly as possible. In residential streets, measures can be limited to making them reasonably passable, to reduce salt use.

1.2 Origin of slipperiness

Slipperiness can arise from

1. Frozen fog deposition
2. Hoar-frost formation through direct condensation
3. Freezing of a wet roadway
4. Subcooled rain
5. Rain on a roadway that is below OC in temperature
6. Icy rain
7. Hail
8. Snow

Of these causes, those listed under 1-7 occur infrequently in the known winter regions, such as Norway, Sweden, and the Alpine area, but they are the most common ones in Netherlands. They bring their own particular problems concerning countermeasures.

1.3 Countermeasures against slipperiness

1.3.1 Frozen fog deposition

Frozen fog deposition occurs if these prerequisites are present:

a. Presence of fog, consisting chiefly of larger water droplets, so that water slowly forms on the roadway.

b. A roadway temperature below the freezing point.

In regard to slipperiness here, the air temperature is not material, but the temperature of the roadway is. Turbulence of the lowest air strata may play a part. For approach ramps and bridge decks in particular, rapid cooling of the roadway will cause the above-mentioned conditions to be satisfied sooner than elsewhere, so that often warnings of slippery conditions are given for these road stretches. Slipperiness generally appears suddenly and is therefore very dangerous. At places

where fog can suddenly occur, such as at river crossings, the above-mentioned conditions for appearance of slipperiness exist, and are aggravated by the lower bridgedeck temperature.

Countermeasures include spreading of salt, and 7-10 g/m^2 appears adequate. Under these circumstances, preventive salting is preferable.

1.3.2 Hoar-frost f[illegible] through direct condensation

In hoar-frost [illegible] the water vapor in the air condenses directly on the cold road[illegible], which becomes covered with numerous ice crystals. This cause of slipperiness is more difficult for the road user and road officials to foresee than that of the frozen fog deposition, because water vapor in the air is invisible and therefore more dangerous. It can be determined by the KNMI* [Weather Service] that in certain zones there is a chance that slipperiness will occur, but it cannot be said that it actually will. This slipperiness is also countered by salt at 7-10 g/m^2.

Preventive spreading is especially appropriate here, because accidents are very serious when slipperiness does occur. The difficulty, however, is that preventive spreading with dry salt on a dry roadway is ineffective, because the salt is immediately removed from the roadway by the traffic.

1.3.3 Freezing of a wet roadway

The preexisting conditions for a slippery roadway because of freezing of a wet roadway are--the terminology expresses it completely--a wet roadway and a roadway temperature below the freezing point. The roadway temperature is influenced by the air temperature, so that if the air

* KNMI means: Royal Dutch Meteorological Institute

temperature drops below the freezing point of a wet roadway, slipperiness may be expected. In addition, radiation to a clear sky can reduce roadway temperature to below the freezing point even when the air temperature is still above the freezing point. In this case, slipperiness appears faster and is therefore more dangerous. Preventive measures are best suited under these circumstances. Measures against slipperiness can be salt at about 10 g/m^2, depending on the amount of ice on the roadway and the roadway temperature.

1.3.4 Subcooled rain and

1.3.5 Rain on a roadway that is below OC in temperature

Subcooled rain is liquid precipitation falling at temperature below freezing and immediately crystallizing as soon as it touches anything. When this rain falls, a very slippery ice layer occurs on the roadway. The same slippery ice layer forms if rain falls on a roadway at temperature below OC. These forms of slipperiness occur in a transition period from frost to thaw and vice versa. Traffic is completely crippled by this slipperiness. Measures against this slipperiness are difficult. The spreader trucks can scarcely move, because the road is blocked by transversely standing cars and trucks, and the salt is not completely effective if traffic over the road is irregular. In addition, plowing cannot remove the ice layer before the salt and traffic have changed the layer to loose melting ice. The most effective measure to counter this slipperiness is the spreading of a mixture of salt and some sand. The salt has the purpose of melting the ice, and the sand adds some roughness, so that traffic can go on the ice before the ice has melted. In continuous rain, the spreading must be frequent because the material spread is quickly covered by an ice layer.

1.3.6 Icy rain

In icy rain, the raindrops descend frozen and form a rough-surfaced ice layer on the roadway. Although this layer is extremely slippery, traction is fairly good. The slipperiness cannot be called very dangerous, because it is evident to everyone. Countermeasures similar to those for slipperiness from subcooled rain can be taken.

1.3.7 Hail

Hail is precipitation in the form of more or less porous ice globules. They never fall for a long period, but always in showers, mostly at a temperature above freezing. Hail does not usually stay long on the road, but it can cause slipperiness which is short-lived unless the air clears shortly after the shower and the temperature falls to near or below freezing; then the slipperiness persists much longer. It is perceivable to everyone on the road, however, and should be reason for reducing speed. In practice, this does not work out.

Hail should be removed by salt and, if much has fallen, by snowplows. The difficulty comes in determining where the hail has fallen. In practice, this slipperiness is difficult if not impossible to counter, and often the countermeasures come too late because the slipperiness has been eliminated by melting in the time between the report and the countermeasures.

1.3.8 Snow

Snow is water vapor agglomerated in crystal form in small or large flakes. It occurs if the temperature of a cloud has fallen below the freezing point and water has gone from vapor to solid. Snow can fall at

temperatures far below the freezing point. In the Netherlands, snow can fall as wet or dry snow. Wet snow, mostly falling in showers, causes no slipperiness if it is in small quantities and the temperature of the roadway is mostly above the freezing point, so that the snow melts. If this snow falls for a long time, a layer of "melted snow" can occur and cause slipperiness. Countermeasures for this slipperiness are preferably plows with flexible wear strips, along with appropriate use of salt.

In countries with a maritime climate, such as ours, very little dry snow may fall in many winters, in contrast to countries with a more continental climate. The roads become impassable rather than actually slippery. The increase in traffic density gives plows less chance to clear snow from the right of way, so that the snow is packed down firmly often. In addition, the drivers ride in tracks in the snow, so that the snow first melts there.

The water melting during the day again freezes at night, resulting in especially slippery patches on the right of way.

The most common countermeasure up to now is spreading of deicing agents to keep the snow loose--in conjunction with moving vehicles-- so that snowplows can remove it. The amount of deicing agent required per square meter depends greatly on roadway temperature and snow thickness but is certainly several tens of grams per square meter. Even more is necessary if the intent is to melt the snow without any plowing.

1.3.9 Summary

Finally, the above can be summarized in the following chart, which gives a general idea of the degree of slipperiness, countermeasures, and amount of deicing agent.

Summary of slipperiness countermeasures on roads in countries with climate resembling that of the Netherlands.

Manner of origin of slipperiness	Degree of slipperiness	Counter-measures	Amount of deicing agent
3.1 Frozen fog deposition	very dangerous	salt spreading	7-10 g/m^2
3.2 Hoar-frost formation by direct condensation	very dangerous	salt spreading	7-10 g/m^2
3.3 Freezing of a wet roadway	very dangerous	salt spreading	app 10 g/m^2
3.4 Subcooled rain	dangerous	spreading of salt/sand mix	
3.5 Rain on a roadway below OC temperature	impassable	spreading of salt/sand mix	
3.6 Icy rain	dangerous, passable	same as 3.4, 3.5	
3.7 Hail	treacherous slipperiness	difficult to clear; plowing and perhaps a little salt	
3.8 Snow a. wet	sometimes slippery	plowing and perhaps a little salt	
b. dry	passable; sometimes very slippery	plowing and salt	40-70 g/m^2

3. COUNTERMEASURES

Two principal types of countermeasures can be differentiated:

1. Roughness-increasing agents, also called mechanical means.
2. Deicing agents.

3.1 Roughness-increasing agents

Of these, there are:

1. Fine gravel
2. Sand or traction sand

3.1.1 Fine gravel

This is often used in countries and regions where a layer of packed snow remains on the roads during the winter. The gravel remains embedded in the snow surface, producing a friction-increasing layer. This layer can maintain itself for a long time if frost continues without snowfall.

In the Netherlands and climatologically similar regions, this method is inapplicable because of the variable climate and the high cost of the material. In addition, there is high danger of damaged auto underbodies from the thrown-up gravel, which can be loose on the surface when the snow melts. Gravel is unsuitable as countermeasure against slipperiness not caused by snow.

3.1.2 Sand or traction sand

Sand is an old agent against slipperiness. Today, however, when emphasis is on the passability of the roadway, the method of spreading sand mixed with salt has become extremely limited. In spite of some advantages, there are too many drawbacks to this method of combatting slipperiness.

Sand can be coarse or fine, but all grades produce some roughness on the frozen surface. Coarse sand is better than fine sand, which is blown away faster by air currents that traffic produces.

Traction sand is unsuitable, or nearly so, because of cost.

To keep sand spreadable at all times, it is often mixed with salt to prevent freezing. The disadvantage of this method is that vehicles

become spattered with sand to varying extent, and the salt can attack auto metal "treated" thusly. After the salt has melted the ice layer, a layer of sand remains on the roadway to reduce roughness noticeably, especially since the roadway is still wet.

Finally, it should not be forgotten that each ton of sand must be heated, mixed with salt, stored, spread, and then in some manner again removed and taken away (dug out of berms). Above all, the sand that disappears in basins and sewers must be removed at high cost.

3.2 Deicing agents

The best-known deicing agents are:

1. Glycerin
2. Urea
3. Sodium chloride
4. Magnesium chloride
5. Calcium chloride

3.2.1 Glycerin

Glycerin is an alcohol. It serves to counter slipperiness on airfield runways. This agent is very expensive, is relatively ineffective, and also requires special spreading equipment. Glycerin is noncorrosive, leading to use on airfields, although it causes some slipperiness in itself.

It is therefore unsuitable for application on roads.

3.2.2 Urea

Urea is a melting agent in granular form, used on airfields because it, like glycerin, is noncorrosive. It is over five times as expensive as road salt, however, and it requires a dry and heated space for loose

storage, because it has a strong tendency to form lumps. For these reasons urea is not considered as a slipperiness countermeasure on roads.

3.2.3 Sodium chloride

In the Netherlands, NaCl is nearly the only deicing agent. It is not expensive and is more effective than $CaCl_2$ if temperatures are not excessively low (to -12C). In countries where $CaCl_2$ is applied, salt is often combined (see 3.2.5). Table 1 shows how much ice is melted at various temperatures by 1 kg salt.

°C	1 kg. ijs
-1	50
-4	14,3
-7	9,1
-12	5,3
-18	3,8
-23	0

Table 1. Maximum ice weight in kg melted by 1 kg NaCl at various temperatures.

Legend: 1. kg ice

Salt storage is no longer a problem, because an anticaking agent is added at the factory, so that as long as the salt is not exposed directly to rain or groundwater, it cannot become hard by freezing above -15C. Fig. 2 shows the phase diagram of the water/salt (NaCl) system. It shows that below -22C, NaCl can no longer melt any ice. This is the reason why pure NaCl cannot be used as a deicing agent in countries with extremely low temperatures (see also 3.2.4 and 3.2.5).

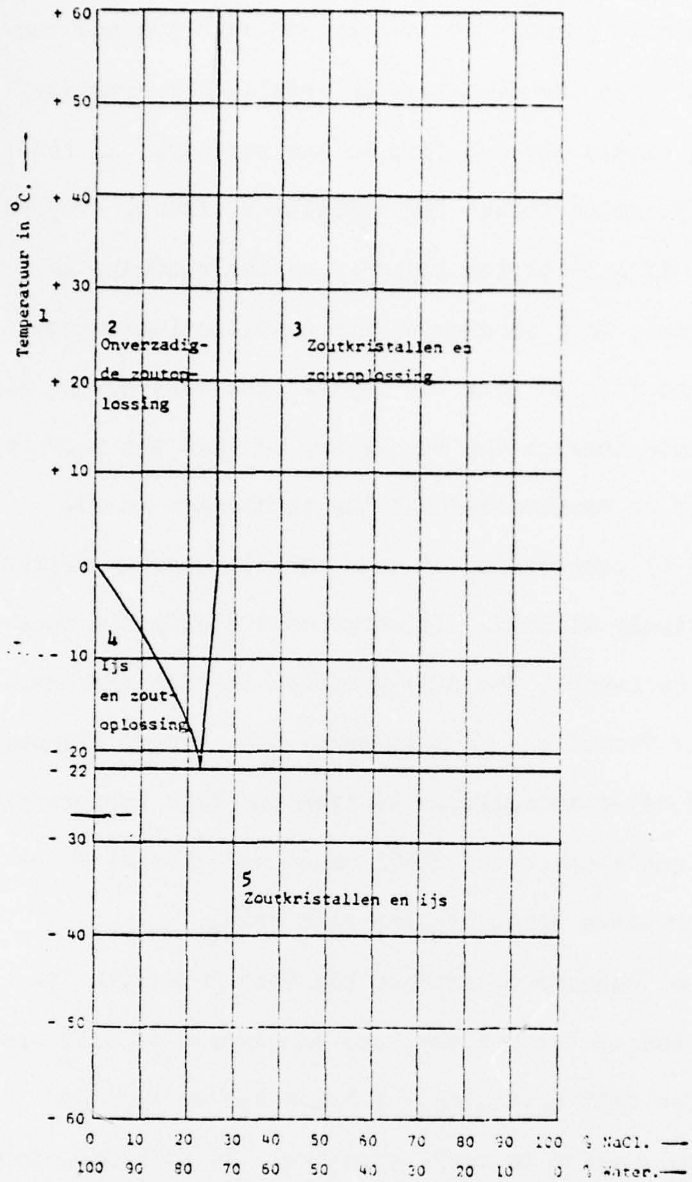

Fig. 2. Ice/NaCl phase diagram.

Key: 1. Temperature in deg C

2. Unsaturated salt solution

3. Salt crystals and salt solution

4. Ice and salt solution

5. Salt crystals and ice

Vacuum salt is fine salt pumped from the ground as brine and vacuum-evaporated. This salt has the advantage of working very rapidly, and it can be applied in finely divided form to the roadway. If little ice is on the roadway, as in frozen fog deposition, frost, etc, vacuum salt performs best. If a thick ice layer is on the roadway, as for packed snow or glazed frost, then because of its quick action vacuum salt rapidly forms a brine film on this ice layer. The salt grains dissolve before they penetrate through the ice layer, so that the road is practically impassable if no roughness-enhancing agents are added.

Rock salt, produced by evaporation of seawater, is coarse-grained. This salt cannot be as finely divided. It works more slowly but penetrates deeper into the ice layer. The fine fraction in this rock salt also produces quick brine formation, so that here, too, a very slippery surface results directly after spreading. To overcome this temporary slipperiness, it is advisable under the above-mentioned circumstances to add 10-20% roughness-increasing agents to the rock salt.

Brine is inadvisable, because experience has been poor with it. Additional water is applied to the roadway, and the amount of salt needed is much larger than for salt spreading. A brine system must be nearly all stainless steel, which is very expensive. Maintenance, too, is very costly.

3.2.4 Magnesium chloride ($MgCl_2$)

3.2.5 Calcium chloride ($CaCl_2$)

These two deicing agents are rarely or never applied in countries where the temperatures at which slipperiness must be countered are mostly above app -10C (including the Netherlands). Both deicing agents are less effective than NaCl at temperatures above app -10C (see Table 3).

At below -10C, however, they are more effective than NaCl. Table 3 summarizes the results of a test on the relation between amount of deicing agent needed, in g/m^2, for the three materials NaCl, $CaCl_2$, and $MgCl_2$. These agents had to melt a 2-mm thick ice layer. Temperature was varied, too. Table 3 shows that at moderately low temperatures (to app -8C) the amount of NaCl can actually be less than the other two agents.

Temperatuur in ^oC	1 Hoeveelheden in gr/m^2		
	NaCl	$CaCl_2$(2	$MgCl_2$(2
-2	70	85	75
-3	105	130	105
-5	170	205	180
-8	270	290	220
-10	325	340	225
-12	370	380	280

Table 3. Key:

1. Amount in g/m^2 2. Not hydrated

At lower temperatures, $MgCl_2$ is clearly the most effective in terms of quantity needed. It should be noted that $MgCl_2$, too, has limited effectiveness as a deicing agent, as Fig. 4 shows. Below -33C, $MgCl_2$ has no melting effect, unlike $CaCl_2$, which maintains its deicing effect to -55C (see Fig. 5). Because the temperature falls to below -33C in so few regions, $MgCl_2$ can be concluded to be the prime deicing agent over a temperature range of of -8 to -32C.

The cost factor plays a very important part, however. The two deicing salts $MgCl_2$ and $CaCl_2$ are about twice as expensive as NaCl to pro-

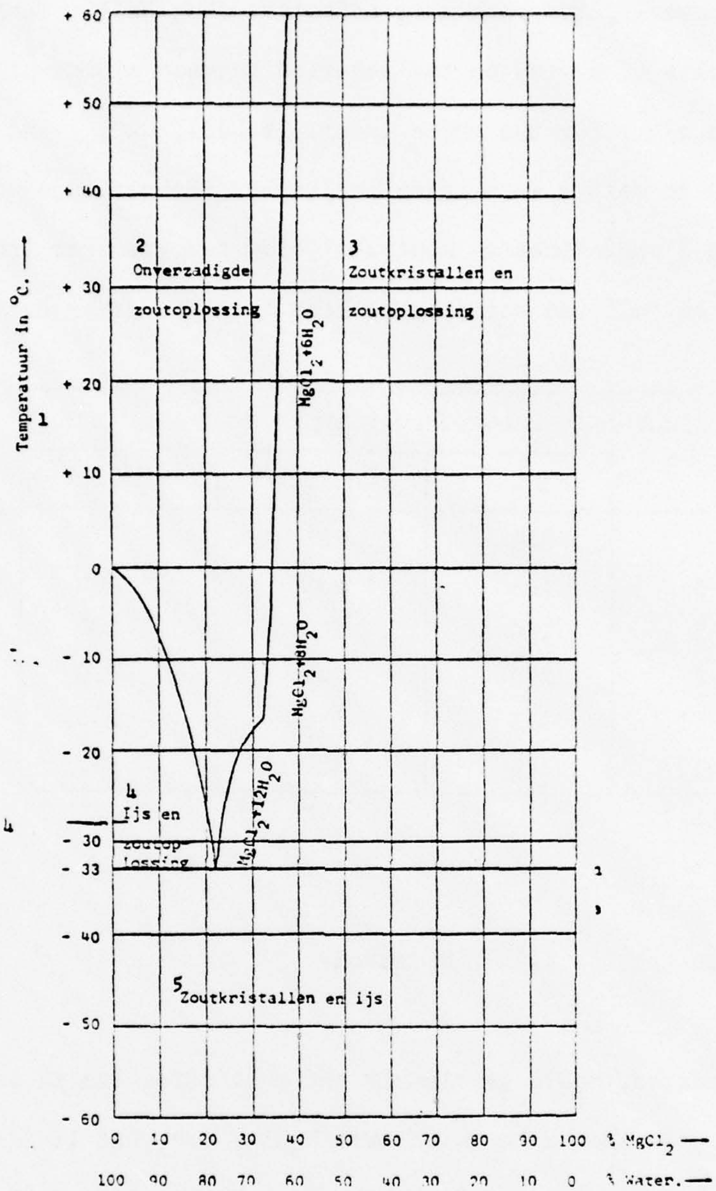

Fig. 4. Ice/$MgCl_2$ phase diagram.

Key: 1. Temperature in deg C
2. Unsaturated salt solution
3. Salt crystals and salt solution
4. Ice and salt solution
5. Salt crystals and ice

duce. Depending on the availability of one of the deicing salts, often a choice is made that will keep expense as low as possible. Use of the most effective deicing agent is the important question. Because both $CaCl_2$ and $MgCl_2$ are hygroscopic, they must be stored in plastic bags or, if loose, in a dry and heated shed.

In recent years, tests have been made, especially in Germany, with mixtures of the two deicing salts NaCl and $MgCl_2$. Various ratios have been studied for their "melting efficiency". The results will be published in a report (Strasse und Verkehr [Road and Traffic]).

4. APPLICATION OF PREVENTIVE MEASURES AGAINST SLIPPERINESS

4.1 Introduction

Although formerly the low traffic densities allowed measures against slipperiness to be limited to keeping the highways reasonably passable, more exacting demands are made today. The amount of deicing salts used annually for countering slipperiness steadily increases. Spreading of salt at 30-40 g/m^2 is scarcely adequate in most cases to melt the ice crust within one to two hours or at least to loosen it. Because thawing of ice crusts and solid snow layers is slow, consideration should be given to substitution of spreading beforehand as much as possible instead of spreading afterward. This means that formation of slipperiness is no longer watched so that it can be countered, but instead the inception of slipperiness is to be prevented. This preventive countering of slipperiness, which is being increasingly introduced, means that reliable meteorological data must be obtained from micromeasuring stations

(slipperiness detectors, etc) if action is to be feasible.

4.2 Melting rate of ice when deicing salts are applied

The melting rate of ice crusts on a roadway depends on many factors. The most important are the the thermal balance of the underlying layers and their thermal conductivity, radiation, air temperature, ice temperature, and amount and type of salt. Of these quantities, a connection can be made among ice temperature, ice thickness, and the amount of salt applied. M P Martin found the following relationship among these quantities for common salt:

$G_s = 16\ TP$, in which G_s is the necessary amount of NaCl, g/m^2, T is the minimum air temperature, C, and P is the ice weight, kg. Factor P is not solely applicable to ice. A weight of 1 kg ice can be assumed equivalent to 1 cm snowfall on 1 m^2 of roadway. This equation is an easily handled and practical rule of thumb. Fig. 1 shows how at constant amount of ice the necessary amount of NaCl increases linearly as the temperature falls, if all ice is to be melted under given conditions. The same linear relationship holds for $CaCl_2$ and $MgCl_2$. In addition, Fig. 1 allows determination of the minimum amount of salt needed to melt the ice completely at a given temperature. It is possible, however, to spread more salt than necessary. The ice then melts faster, and the roadway is normally passable sooner. At the temperature limit at which NaCl is still effective, we find 304 g/m^2 of salt (see Fig. 1). It is clear that this amount of salt is impermissible for the road.

Fig. 2 gives the amount of ice melted in percent as a function of the necessary melting time in minutes. The maximum amount of salt for 1-mm thick ice is:

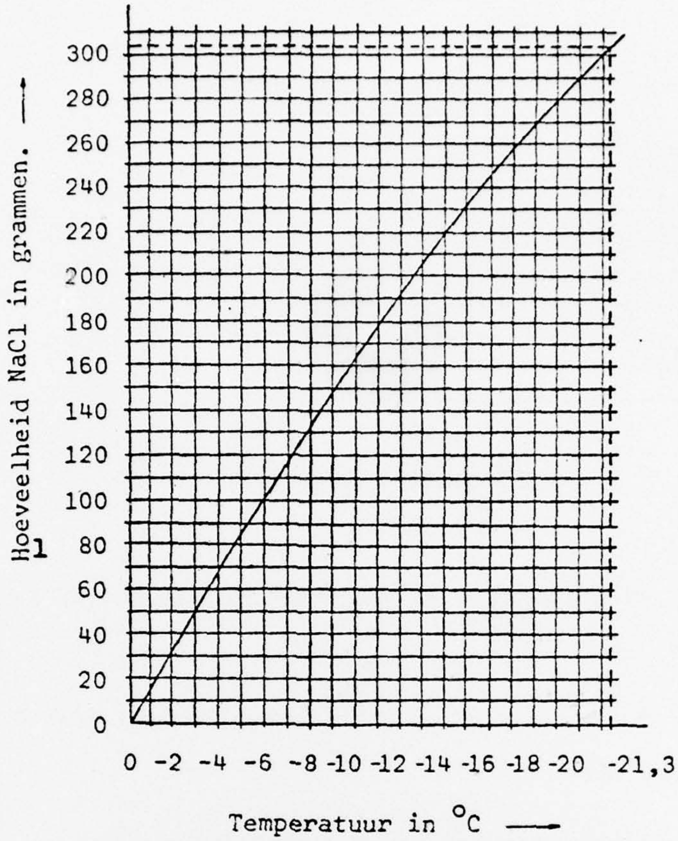

Fig. 1. Relationship between NaCl amount in grams and air temperature in C for ice 1 mm thick.

Key: 1. Amount of NaCl, g

G_s = 16 TP = 16 (21.3) 0.1 = 304 g/m^2. For 2.1 mm ice: G_s = 304d =304(2.1) = 638 g/m^2. This amount is used to set up the relationship given in Fig. 2. To melt all the ice (100%) at -5C temperature requires 30 min.

If the minimum requirement of salt is used to melt a given ice quantity, the melting time becomes unacceptable (see Fig. 3). This means

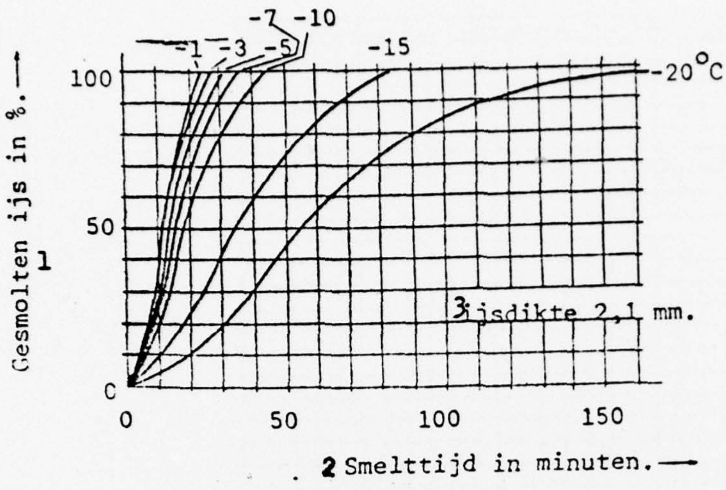

Fig. 2. Melting time as a function of temperature. Amount of salt: 638 g of NaCl per m^2.

Key: 1. Melted ice, % 3. Ice thickness, 2.1 mm

2. Melting time, min

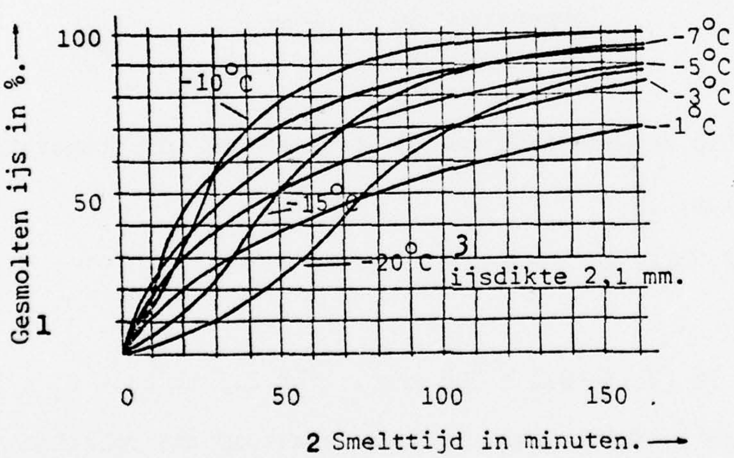

Fig. 3. Melting time at various temperatures for minimum amount of NaCl.

Key: 1. Melted ice, % 3. Ice thickness, 2.1 mm

2. Melting time, min

that from the time of spreading, a water film stands on the ice layer and the coefficient of friction of this "slide path" is less than that of the untreated dry ice.

Finally, a note on melting of ice on concrete and asphalt. Fig. 4 shows that the thawing time for ice crusts of various thicknesses, with

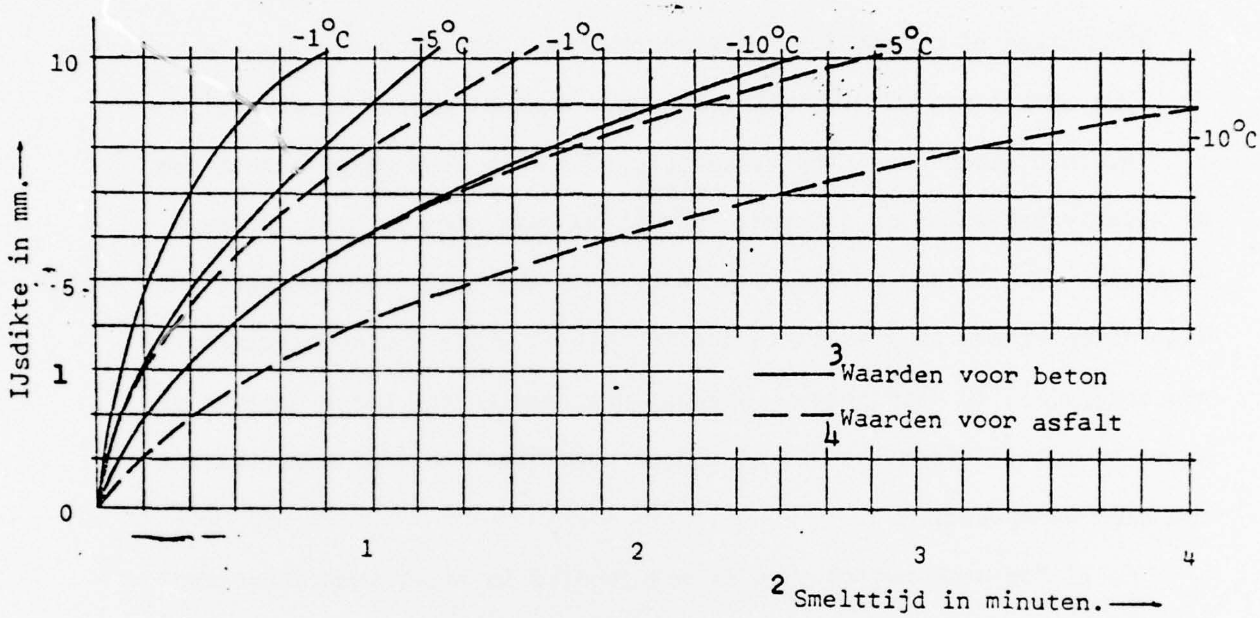

Fig. 4. Melting time as function of various ice-layer thicknesses on concrete and asphalt.

Key: 1. Ice thickness, mm — 3. For concrete

2. Melting time, min — 4. For asphalt

given spreading densities, is different for concrete and asphalt. An explanation for this may be found by comparing the temperature equalization coefficient for concrete and asphalt. The temperature equalization coefficient, defined as $\lambda/\rho c$, is higher for concrete than for asphalt.

For concrete, λ = 2.0W/mK; ρ = 2400 kg/m^2; c = $\pm$ 900 J/kgK

$\lambda/\rho c = 2.0/[(2400)\ 900] = 0.92 \times 10^{-6}$ m/sec.

For asphalt: $\lambda = 0.6$ W/mK; $\rho = 2100$ kg/m^3; c = $\pm$ J/kgK

$\lambda/\rho c = 0.6/[(2100)\ 1100] = 0.26 \times 10^{-6}$ m/sec.

Heat is needed to melt ice, and the higher-conductance concrete can conduct this heat faster than asphalt.

4.3 Advantages of preventive measures against slipperiness

The advantages of preventive measures against slipperiness are:

a. In a given case, the occurrence of ice or snow slipperiness can be totally prevented or delayed. The plows gain time to take further measures. The danger period, extending from the instant of recognition that slipperiness is present to the instant at which the countermeasures are concluded, is eliminated. Hydroplaning—which can occur because of water on intact sheet ice—is no longer possible. In addition, traffic can flow unimpeded.

b. If for some reason snow is not removed in time, then subsequent removal of the solidly packed snow is easier, because the tight adherence to the roadway is broken. In some cases, there is no firmly adherent packed snow, but a snow layer forms which is removed by the traffic itself.

c. Preventive spreading of salt results in minimum amounts of salt. It is then unnecessary to rely on melting periods, which are too long. In addition, there are fewer complaints about draining of oversalty sewer water, and the plants in the road berms have less trouble from high NaCl concentration in the ground water.

4.4 Disadvantages of preventive measures against slipperiness

a. There is a risk that salt will be spread on the basis of information obtained, but that changes will occur suddenly in weather conditions, so that salt spreading would not have been necessary.

b. Removal of salt from the roadway before it meets the expected precipitation on the roadway. This removal can be the result of the wind or of air turbulence that accompanies a stream of traffic.

4.5 Conditions for economically justifiable preventive measures against slipperiness

Precise derivation of slipperiness forecasts that are representative of certain regions or road stretches is the most important condition. Specially trained personnel must be available for this, familiar with the regional climate conditions, able to read the instrument recordings of the specially equipped stations, and able to interpret these data precisely, along with the meteorological data of the weather service. There is no doubt that there must be a closely coordinated reporting system and countermeasures system. The condition of the deicing salt is very important. It must be capable of long-term adherence to the roadway, even if the salt is exposed to traffic-produced turbulence. Fine salt grains that remain adhered in pores in the roadway best meet this requirement.